

Fluid resuscitation in burns: an update

更新燒傷的輸液復甦

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Fluid resuscitation has been a mainstay in the treatment of major burns for over 50 years. Fluids must be commenced as soon as possible prior to transfer to a specialist unit in order to minimise burn wound conversion and reduce the incidences of burn shock, post-burn renal failure, life-threatening electrolyte disturbances and mortality. Due to the lack of robust evidence, uncertainty exists regarding the type of fluid, the rate of fluid administration and method of monitoring fluid resuscitation in these patients. The advances in our understanding of burn pathology and technology may have rendered fluid resuscitation formulae, such as the Parkland, obsolete. This review aims to provide an up-to-date summary on the controversies and advances in burns fluid resuscitation to aid the emergency practitioner to make informed decisions. (*Hong Kong j.emerg.med.* 2009;16:51-62)

輸液復甦作為嚴重燒傷的主要治療已超過50年。轉送專科單位前必須盡早開始輸液，以減低燒傷傷口的轉變及減少燒傷休克，燒傷後腎衰竭和威脅生命的電解質失調的發病率及死亡率。由於缺乏強力的證據，關於這些病人輸液的種類，輸液的速率及輸液復甦監察的方法仍未能確定。我們對燒傷病理學的理解及科技的進步，可能已使輸液復甦的公式過時，如帕克蘭公式。這評閱是一個包含最新信息的摘要，旨在提供燒傷輸液復甦的爭議及發展，以幫助急症從業員作知情的決定。

Keywords: Burns, fluid therapy, oedema, resuscitation, shock

關鍵詞：燒傷、輸液治療、水腫、復甦、休克

Introduction

Fluid resuscitation has been a mainstay in the treatment of major burns for over 50 years. Due to the lack of robust evidence, uncertainty exists regarding the type of fluid, the rate of fluid administration and method of monitoring fluid resuscitation in these patients. This review aims to provide an up-to-date summary on the controversies and advances in burns fluid resuscitation to aid the emergency practitioner to make informed decisions. We searched Medline using keywords related

to fluid management in burns and we also back-referenced from publications.

Pathophysiology

The key to any development in burns management lies in a better understanding of burn pathology and its dynamic and reciprocal relationship with fluid management (Figure 1). Burn injuries of at least partial-thickness in depth, exceeding 15-20% total body surface area (TBSA) in the adult, and 10-15% TBSA in the child, disrupt homeostasis and lead to a complex cascade of events that culminates in a systemic inflammatory response orchestrated by the release of inflammatory mediators (Figure 2). Consequently, massive fluid shifts occur, leading to life-threatening haemodynamic and electrolyte changes. Potential sequelae include burn shock and oedema formation.

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Patient outcome depends upon patient factors, the nature of the injury and treatment. Patient factors include pre-morbid physiological status and genetic make-up, both of which determine the ability to mount a compensatory stress response. The nature of the burn injury relates to the burn size, depth and presence of concomitant injuries, such as inhalation injuries, which can dramatically alter fluid requirements (Table 1).

Table 1. Factors that increase resuscitative fluid needs in burn patients

- Inhalation injury
- Delay in resuscitation
- Crush injury
- Electrical injury
- Large full-thickness burn
- Associated injuries

Burn shock

Prior to the introduction of fluid therapy, intravascular hypovolaemia leading to acute renal failure was the commonest cause of death in major burns.¹ Fluid resuscitation was therefore introduced as supportive therapy to restore intravascular volume and maintain physiological parameters, including mean arterial pressure and urine output, within normal limits. The principle was to ensure adequate delivery of oxygen and nutrition to tissues, maintain end-organ perfusion and hence improve survival.

It was later discovered that fluid shifts from the intravascular to interstitial compartments occurred according to changes in Starling forces. The main changes are, firstly, an increased capillary permeability secondary to compromised microvascular endothelial integrity, and secondly, the development of a strongly negative tissue "imbibition" pressure due to

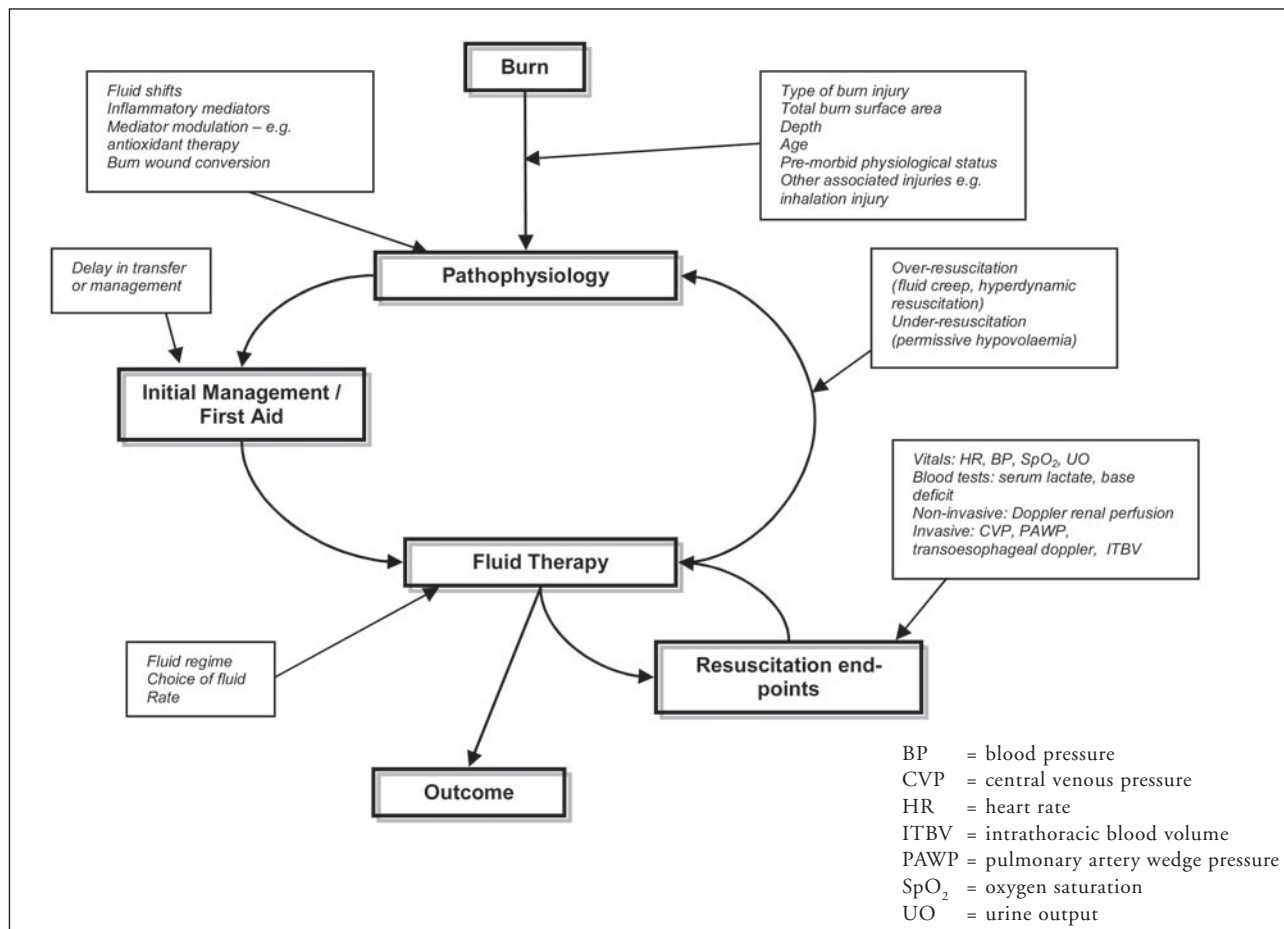


Figure 1. Burn pathophysiology and its relationship with fluid management.

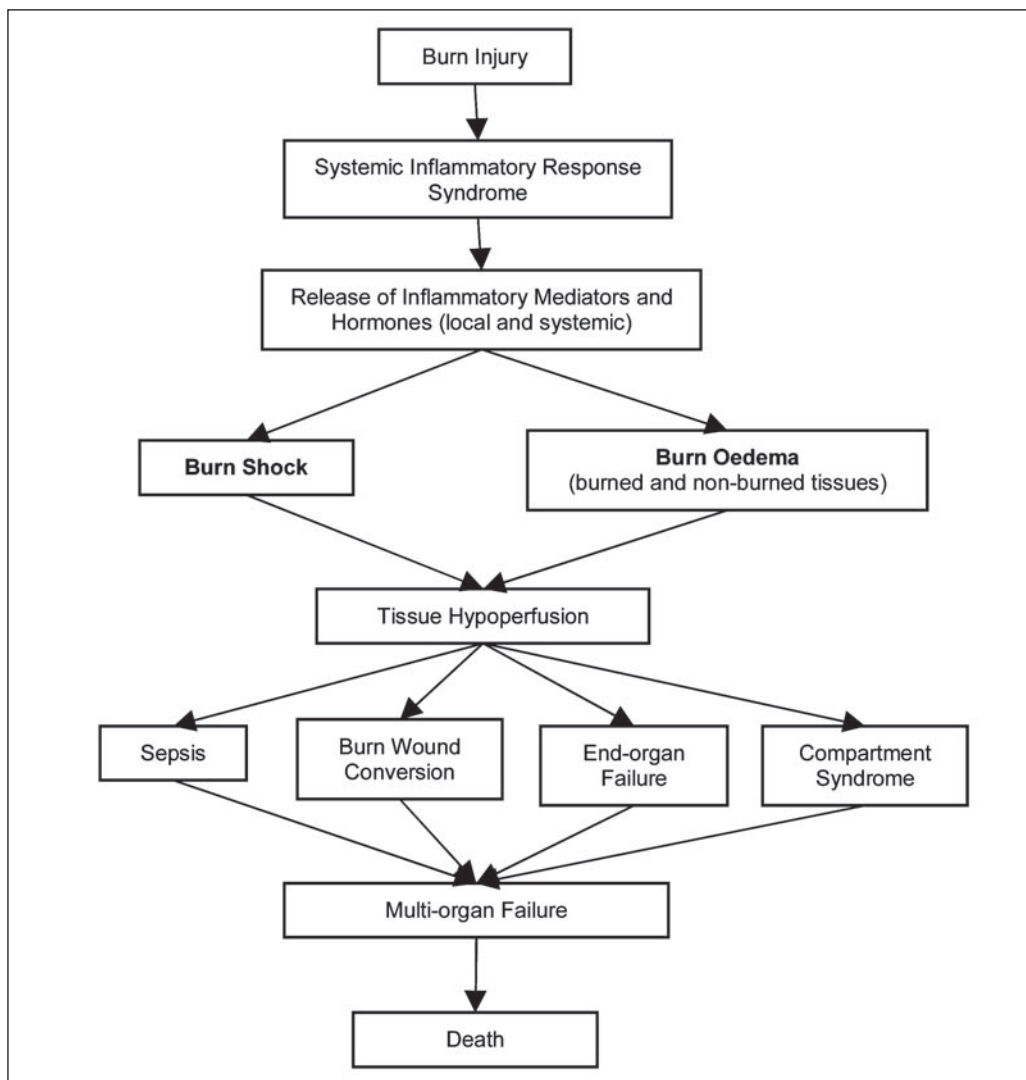


Figure 2. Events after burn injury.

denaturation of collagen and changes to thermally injured tissues. Inflammatory mediators released also cause myocardial dysfunction² and elevate systemic vascular resistance,³ culminating in the state of "burn shock" which places susceptible organs, including the kidneys, at risk. Therefore, without early and sufficient fluid resuscitation, acute renal failure, cardiovascular collapse and death will likely ensue.

Burn oedema

As far back as 1799, Earle recognised the importance of minimising oedema formation following burn injury.⁴ Burn oedema is a product

of inflammation and occurs both locally in burnt tissues and systemically in non-burnt tissues. It is detrimental because it increases transport distances for oxygen, substrates and waste products, and inhibits blood perfusion (Table 2). Local oedema formation occurs immediately post-burn and oedema in non-burned tissues occurs during the first 12-24 hours and can account for up to half the fluid resuscitation volume in 50% burns.²

Baxter later discovered that oedema formation in non-burned tissues, leading to distant organ dysfunction, was a result of a systemic decrease in cellular transmembrane potential.⁵ Therefore, the use of

crystalloids was introduced in an attempt to restore the transmembrane potential and prevent cell death. It follows that the extent of oedema depends on the severity of the burn injury and adequacy and type of fluid resuscitation.⁶ It was also observed that the extent of tissue water content correlated with hypoproteinaemia during the early resuscitation period and its persistence after restoration of normal permeability may be a result of sustained hypoproteinaemia.⁷

Table 2. Complications of burn oedema

- Pulmonary hypertension and oedema
- Airway compromise
- Compartment syndromes, including airway, limbs and abdomen
- Escharotomy
- Hypoperfusion
- Gastrointestinal tract dysfunction
- Burn wound conversion
- Delayed wound healing
- Predisposition to infection and sepsis
- Cerebral oedema in children
- Reduced mobility

Fluid therapy

Fluid resuscitation aims to support the patient through the initial 24-48 hour period of burn shock by:

- Re-expanding the intravascular volume,
- Delivering adequate amounts of sodium to restore cellular transmembrane potential,
- Replacing other extracellular electrolytes, thereby preventing life-threatening electrolyte disturbances that can lead to cardiac arrhythmias, and
- Correcting hypoproteinaemia and increasing colloid oncotic pressure.

The British Burns Association advocates the use of the Parkland formula although numerous other fluid resuscitation formulae are also available (Table 3). As Muir and Barclay emphasised, any fluid regime must be viewed as guidance rather than rule and fluid administration must be carefully titrated against physiological response.⁸

One of the greatest challenges in fluid therapy is to achieve adequate resuscitation i.e. critical perfusion of end-organs, whilst preventing over-resuscitation which exacerbates burn oedema formation.

Table 3. Fluid resuscitation formulae

Colloid formulae	Electrolyte	Colloid
Evans	Normal saline 1.0 ml/kg/%TBSA	1.0 ml/kg/%TBSA
Brooke	Lactated Ringer's 1.5 ml/kg/%TBSA	0.5 ml/kg/%TBSA
Slater	Lactated Ringer's 2 L/24 hours	
Crystalloid formulae		
Parkland	Lactated Ringer's 4 ml/kg/%TBSA	
Modified Brooke	Lactated Ringer's 2 ml/kg/%TBSA	
Hypertonic saline formulae		
Hypertonic saline solution (Monafo)	Maintain UO at 30 ml/h Fluid contains sodium 250 mmol/L	
Modified hypertonic (Warden)	Lactated Ringer's + 50 mmol/L NaHCO ₃ for 8 h to maintain UO at 30-50 ml/h Lactated Ringer's to maintain UO at 30-50 ml/h beginning 8 h post-burn	
Dextran formula (Demling)	Dextran 40 in saline – 2 ml/kg/h for 8 h Lactated Ringer's – maintain UO at 30 ml/h FFP – 0.5 ml/kg/h for 18 h beginning 8 h post burn	

FFP=fresh frozen plasma; TBSA=total body surface area (burns); UO=urine output

Therefore, accurate monitoring of resuscitation endpoints is vital. In reality, all fluid types that have been advocated are able to effectively restore tissue perfusion but there are certain situations when a particular solution may be more appropriate. The development of newer fluids and the use of different fluids during different post-burn phases have added to the challenge of discovering the optimal fluid regime for burns.

Controversies exist in the choice of fluids (Table 4), and the aggressiveness and monitoring of fluid resuscitation.

Crystalloids

Lactated Ringer's solution

A crystalloid is an aqueous solution of crystalline

Table 4. Fluid choices

Fluid	Advantages	Disadvantages
Lactated Ringer's	Cheap Safe Readily available Lactate buffers metabolic acidosis	Isotonic, only 25% remains intravascularly No plasma expansion properties No protein replacement Contributes to burn oedema May require more fluid to maintain physiological parameters compared to other fluids
Hypertonic saline/sodium	Plasma expansion May decrease burn oedema Restore cellular transmembrane potential	Hypernatraemia and hyperosmolar state No protein replacement Hypertonicity may dehydrate cells Progressive burn wound necrosis Transient plasma expansion
Albumin (5% or 25%)	Naturally occurring colloid Strong oncotic properties Replenishes protein deficiencies Decreases oedema Reduced fluid requirements	Expensive May increase interstitial and pulmonary oedema if given in first 8 hours post burn Transmissible blood-borne diseases
Fresh frozen plasma (FFP)	Naturally occurring colloid Plasma expansion Replenishes protein deficiencies Decreases oedema	Limited availability Transmissible blood-borne diseases
Dextran and starches	Synthetic colloid of high molecular weight Decreases oedema Plasma expansion Reduced fluid requirements Cheaper than albumin and FFP	Risk of allergic reaction May interfere with blood typing Impair coagulation Dextran 40 is associated with acute renal failure Cannot use urine output as guide to resuscitation adequacy No protein replacement, may worsen hypoproteinaemia Volume expansion effect dissipates upon discontinuation of infusion
Starches (pentastarch, pentafraction, hetastarch /Hespan)	Synthetic colloid 6% solution (hyperoncotic compared to 5% albumin) Low risk of allergic reaction Improved retention of colloid in intravascular space Cheaper than albumin and FFP	Capillary "sealing" effect – inhibits capillary leak Pentafraction and pentastarch have less effect on coagulation than hetastarch No protein replacement May alter coagulation in large doses

substance capable of diffusion through a semi-permeable membrane. Crystalloids are safe, cheap and widely available. Hartmann's (or Lactated Ringer's) solution is the preferred first-line fluid recommended by the British Burns Association. Its composition and osmolality closely resemble normal bodily physiological fluids and it also contains lactate which may buffer metabolic acidosis in the early post-burn phase. However, its isotonicity means that it leaks through capillaries into the interstitial space and only 25% of the infused volume remains within the intravascular compartment. Furthermore, it contains no protein and hence exerts no oncotic pressure, which may exacerbate oedema formation in states of severe hypoproteinaemia as seen in burns. This has been a concern particularly in the context of pulmonary oedema, but various studies using the transpulmonary double indicator dilution method (which measures fluid accumulation within the lung) have rejected this.^{9,10} Furthermore, its association with oedema formation may contribute to organ dysfunction, compartment syndrome of the extremities, airway and abdomen, and acute respiratory distress syndrome. Nevertheless, there is yet to be any convincing evidence to show that alternative fluids are better.

Hypertonic saline

The use of hypertonic solutions in burn resuscitation was introduced by Monafó.¹¹ The rationale was to increase intravascular osmolality in order to reverse the fluid shifts, thereby restoring haemodynamics and minimising burn oedema formation. Demling demonstrated that smaller amounts of fluid could be given with an equivalent improvement in intravascular volume.¹² Hypertonic saline (HS) has been shown in one study to reduce the risk for abdominal compartment syndrome whilst maintaining an adequate urine output with lower volumes of resuscitation fluid when compared to the Parkland regime.¹³ Furthermore, hypertonic saline may improve myocardial contractility, by quickly restoring cell membrane potential, and also reduce vascular resistance.¹⁴

Despite these advantages, routine HS use is uncommon. The restoration of haemodynamics is mostly transient (unless colloid is used in addition). A

prospective randomised study of patients with 20% TBSA burns evaluating hypertonic sodium lactate versus Lactated Ringer's solution did not demonstrate decreased fluid requirements.¹⁵ Furthermore, serious adverse effects can occur with rapid infusions, including severe hypernatraemia and hyperosmolality, leading to renal failure, myocardial fluid overload, brain shrinkage, seizures and intracranial vessel rupture. Despite the lack of evidence, hypertonic crystalloid continues to be popular in infant and elderly patients in whom there is little risk of hypernatraemia.^{16,17}

A study by Huang et al¹⁸ found that HS is associated with a four-fold increase in renal failure and two-fold increase in mortality. It has also been suggested that it causes progressive wound necrosis.¹⁹ Recent systematic reviews^{20,21} concluded that there was insufficient data to settle the debate over whether hypertonic was better than isotonic crystalloid for burn resuscitation. However, Brown, in his review of 17 trials, noted that the confidence intervals were wide which meant that clinically important differences might exist.²⁰ One major problem for comparative analysis is that there is no standardisation of hypertonic saline administration, neither in terms of fluid composition nor rate of infusion.

Colloids

Colloids consist of either naturally-occurring protein solutions, such as albumin, fresh frozen plasma and blood, or synthetic non-protein solutions, such as dextrans and starches. Their plasma expansion property is thought to confer an advantage over crystalloids by exerting an oncotic pressure across the capillary membrane and hence reducing oedema formation.²² The protein-containing solutions are also able to replace serum protein deficiencies.

Albumin

Albumin solution is the most commonly used colloid. It is negatively-charged and therefore repelled by the negatively-charged endothelial glycocalyx, extending its intravascular duration. As well as being an important serum transport protein, it scavenges free radicals and possesses anticoagulant properties. In health, it contributes approximately 80% of the plasma oncotic pressure but in the critically ill, serum albumin

correlates poorly with colloid oncotic pressure. It is expensive but has a long shelf-life and there is a risk of disease transmission including prion Creutzfeldt-Jakob disease. Two concentrations 4.5% and 20% from pooled donors are available. The half-life of exogenous albumin in the circulating compartment is 5-10 days, assuming an intact capillary wall membrane. In the critically ill, capillary leak limits its effectiveness, at least during the initial 8 hours post-burn. Demling showed that albumin increased intravascular volume better than Lactated Ringer's solution and reduced oedema in uninjured tissue.²²

Non-protein colloid solutions: dextran and starch resuscitation solutions

Dextrans consist of high molecular-weight glucose polysaccharides and are designed to restore intravascular oncotic pressure. Starches, such as pentafractan, are thought to possess a "sealing property" that counters capillary permeability, thereby reducing interstitial oedema, but these effects are limited, for example, Dextran 70 has an intravascular half-life of 12 hours only. In addition to plasma expansion, they may improve microcirculatory blood flow by reducing blood viscosity, platelet adhesion and coating of the endothelial surface, although their effects on coagulation may be problematic. Dextrans can also precipitate acute renal failure via tubular obstruction, interfere with cross-matching and trigger allergic and anaphylactic reactions.

Blood

Blood is an appropriate replacement fluid following severe haemorrhage and can be used to increase the haemoglobin concentration in the circulation and improve oxygen carriage. Transfusion expands the intravascular compartment with little or no increase in interstitial fluid but is potentially dangerous with risks of disseminated intravascular coagulopathy, severe renal injury and disease transmission. Furthermore, it is in short supply, expensive, antigenic and requires cross-matching and storage facilities.

Haemoglobin-based blood substitutes

More recently, haemoglobin-based blood substitutes, such as disaspirin cross-linked haemoglobin, have been

developed. They are infusible, oxygen-carrying fluids that have long shelf-lives and no need for refrigeration or cross-matching. Polymerisation of haemoglobin improves intravascular persistence with a half-life of 24 hours. They display similar oxygen-dissociation curves to blood and are free from disease transmission. Polymerised bovine haemoglobin, HBOC-201, has been well-tolerated in clinical trials and has been licensed for clinical use in South Africa. These fluids can be life-saving in Jehovah's witnesses. However, recent data have shown a significantly increased risk of death and myocardial infarction without clinical benefit.²³

Crystalloids versus colloids

The crystalloid vs. colloid debate represents one of the longest-standing controversies in burns fluid management and a thorough account is beyond the scope of this article. However, several recent reviews have revived this debate and are worth mentioning.

Although colloids remain in the circulation longer than crystalloids, impaired capillary membrane integrity during the early phase (within 8 hours) of burn injury leads to mass extravasation of plasma proteins, including albumin. This means that iatrogenic replacement of proteins during this period of hypoproteinaemia is futile and may even exacerbate burn shock and oedema by increasing interstitial oncotic pressure. Treatment of hypoalbuminaemia with albumin has not been shown to alter the outcome in the critically ill. Smaller molecular weight colloids including albumin may not be useful but there may be a role for larger molecular weight hydroxyethyl starches.

Non-burned tissues appear to recover their membrane integrity between 8 and 24 hours post-burn depending on the adequacy of fluid resuscitation and level of systemic response. Therefore, delayed colloid infusions, if necessary, may be commenced at 8 hours post-burn, although the exact timing remains controversial. Many investigators advocate the use of colloids when large total fluid volumes are anticipated such as in inhalation injuries or large burns, children and the elderly, or those demonstrating refractory burn shock.²²

While various trials and systematic reviews, including two Cochrane reviews, have found no evidence that colloids or albumin are associated with an improvement in the survival of critically ill patients, including burn victims,^{24,25} some have reported an increased mortality associated with the use of albumin. Unfortunately, these reviews have been fraught with methodological errors and limitations with the use of different end-points and physiological protocols for fluid administration, circulatory and respiratory treatment. Furthermore, there was inappropriate grouping of study treatments. Nevertheless, this does not preclude the possibility that there exists highly-select sub-groups of critically ill patients in whom colloids may be beneficial. Despite the lack of robust outcome data, albumin remains the mainstay of colloid therapy in some paediatric intensive care units.

Aggressiveness of resuscitation

Since the introduction of the Parkland formula, there has been much evidence to show that fluid volumes infused are far removed from the Parkland estimates. Recent buzz-terms include "fluid creep", "permissive hypovolaemia" and "hyperdynamic resuscitation". These have arisen as a result of studies with apparently contradictory results.

Careless fluid resuscitation can lead to life-threatening complications. Under-resuscitation leads to hypovolaemic shock, acute renal failure, wound conversion, end-organ failure and sepsis, all of which are associated with a high mortality rate. More recently, however, attention has shifted to the complications of over-resuscitation (Table 2 and Figure 3).

Fluid creep

'Fluid creep' is a term coined by Pruitt which describes the trend of providing fluids in excess of the estimated volumes using fluid formulae.²⁶ This may in part be explained by the increasingly routine use of invasive monitoring and has been thought to be associated with major complications, including compartment syndromes (which may necessitate early tracheal intubation, fasciotomy and abdominal decompression when the airway, distal extremities and abdomen are involved respectively), pulmonary oedema, prolonged mechanical ventilation, and graft failure.²⁷⁻²⁹

One recent multicentre study has demonstrated that large volumes of resuscitation fluid are associated with increased risk of infectious complications, acute respiratory distress syndrome and death.²⁷ However, how well the statistical models adjust for the injury and patient characteristics that confound the relationship between fluid resuscitation and outcome is unclear. It is particularly important to achieve and maintain this dynamic resuscitation balance in burn victims with limited physiological reserves, such as the elderly, children and those with significant comorbidities or concomitant injuries.

Permissive hypovolaemia

Recognition of these complications of over-resuscitation led to the concept of "permissive hypovolaemia".³⁰ Lund advocated avoiding excessive fluid administration during the early post-burn phase to minimise burn oedema.³¹ The success of a current "low volume" resuscitation regime was demonstrated by the presence of early post-burn acute renal failure in only 2 of >2100 burn patients in a tertiary care burn centre.²⁹ Between 1994-2004, dialysis was required for either early or late onset acute renal failure in only 10 of 3266 burn patients (0.3%) treated at the U.S. Army Burn Centre.

Hyperdynamic resuscitation

By contrast, various studies using invasive monitoring have suggested that the Parkland formula underestimates fluid requirements,¹⁰ that significant additional volumes were in fact necessary to meet physiological end-points^{9,10} and that deliberate and controlled over-resuscitation, including the use of vasopressors, led to improved survival and a reduced incidence of end-organ damage.³² The aim is to achieve a supra-normal cardiac index so that the increase in oxygen delivery to the tissues overcomes the impaired oxygen uptake that occurs after burn injury.

Shoemaker et al demonstrated that patients resuscitated to "hyperdynamic endpoints", i.e. supranormal cardiac index, oxygen delivery index (DO₂I) and oxygen consumption index (VO₂I), had decreased mortality, intensive care bed stay and ventilator days when compared to patients who were resuscitated to normal haemodynamic values.³³ Failure to reach the set

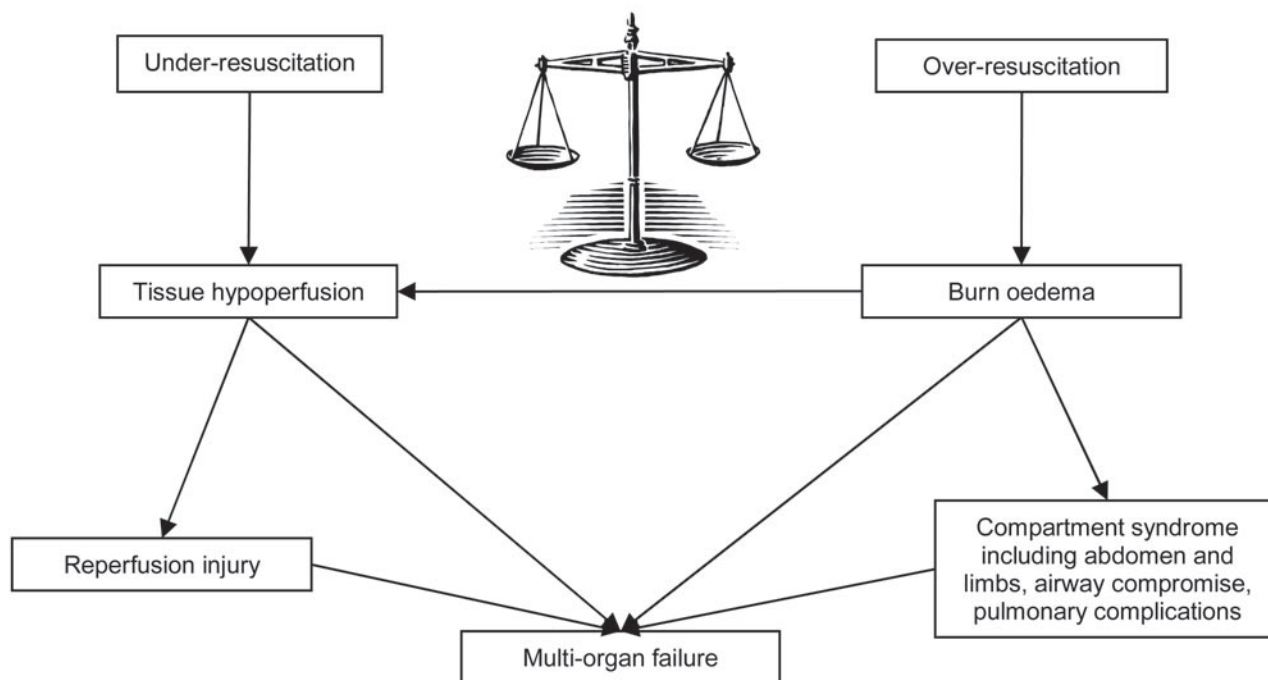


Figure 3. Complications of under- and over-resuscitation.

hyperdynamic endpoints was thought to be a marker of non-survival. Recent studies by Fleming et al provided similar results and in addition, demonstrated a reduced incidence of organ failure.^{33,34} However, two prospective randomised trials were unable to demonstrate a survival benefit or difference in the incidence of organ failure or intensive care unit days.^{35,36} Moreover, opponents to hyperdynamic resuscitation remain concerned about the aforementioned complications of over-resuscitation.

Monitoring resuscitation

Monitoring of burn shock resuscitation is essential for the assessment of the effects and optimisation of fluid therapy. There are growing concerns over the reliability of traditional physiological parameters, both non-invasive and invasive, to assess systemic and end-organ perfusion. This has in part been responsible for the debate over the aggressiveness of fluid administration. All current resuscitation formulae are based on achieving a certain urine output target but do not take into account other important variables including burn depth, pre-morbid physiological status and presence of concomitant injuries (Table 1).

Traditional methods

The level of monitoring depends upon the individual patient, with the sicker burn victim warranting more invasive monitoring. Various studies have rejected the traditional non-invasive parameters (Table 5) including vital signs and urine output as adequate markers of volume status or organ perfusion.³⁷ For example, blood pressure may be maintained until 30-40% depletion of circulatory volume and tachycardia may be secondary to hypovolaemia but also catecholamine release. Although urine output may be a poor indirect indicator of renal perfusion, various groups have

Table 5. Traditional criteria for adequate fluid resuscitation

Blood pressure	Normal
Urine output	1-2 ml/kg/h
Blood lactate	<2 mmol/L
Base deficit	<-5
Gastric intramucosal pH	>7.32
Central venous pressure	0-10 mm Hg
Cardiac index (CI)	4.5 L/min/m ²
Oxygen delivery index (DO ₂ I)	600 mL/min/m ²

nonetheless developed closed-loop resuscitation systems to titrate fluid therapy to a target urine output using a digital urinary output monitor and intravenous pump. Doubts have also been cast over the reliability of invasive monitoring techniques including central venous pressure, pulmonary artery wedge pressure and right ventricular end-diastolic volume.^{10,38}

Newer methods

There is much interest in developing accurate end-points of resuscitation to allow direct measurement of the circulatory volume status and end-organ perfusion with immediate feedback to enable accurate titration (Table 6). Simple laboratory tests such as base deficit and serum lactate have received renewed interest.³⁹

They reflect metabolic state and may be used as markers of tissue perfusion and regularly monitored with continuous intra-arterial blood gas monitoring.

Promising recent advances include power Doppler ultrasound and intrathoracic blood volume (ITBV). Power Doppler ultrasound is non-invasive and has been shown to be a superior measure of renal cortical microvascular perfusion than urine output in the animal model.⁴⁰ ITBV requires only a central venous line and an arterial fibre-optic thermistor catheter inserted into the femoral artery and measures the combined volume of left heart, right heart and pulmonary blood volumes at end-diastole. It has been put forward as a clinically useful indicator of overall

Table 6. Modern resuscitation end-points

End-point	Description	Method	Limitations
Base deficit	Measurement of acid-base balance	Arterial blood gas	Non-specific Predicts morbidity Not proven to alter outcome
Serum lactate	Product of tissue hypoperfusion and anaerobic respiration	Central blood sample analysed within 15 min	Not available in all centres Non-specific
Gastric tonometry	Measurement of gut mucosal pCO ₂ and pH	Nasogastric tube with air- or saline-filled CO ₂ permeable balloon and blood gas analyser or capnometer	Indirect measurement of gut mucosa Long equilibration with saline balloons No enteral feedings No consensus on method or parameters to use
Intrathoracic blood volume	Right heart, left heart and pulmonary end-diastole volumes as indicator of circulatory status	Central venous line and thermistor-tipped fiberoptic arterial catheter	
Trans- and subcutaneous tissue oxygenation	Measurement of tissue O ₂ , pH, pCO ₂ or SaO ₂	Electrodes or optodes applied to skin surface or subcutaneous tissue	Still a research tool Subject to environmental interferences Burn wounds, dressings and oedema may limit use
Optical tissue oxygenation	Measurement of tissue O ₂ , pH, pCO ₂ , SaO ₂ , microcirculation imaging and active compounds by emitted light	Near-infrared spectroscopy, orthogonal polarization spectral imaging, magnetic resonance spectroscopy or optodes	Still a research tool No quantitative reference values Costly Not easily accessible

cardiac preload.^{10,38} It may be particularly useful in the complex setting of the critically ill, burn patient with cardiac dysfunction and a requirement for mechanical ventilation and has been the basis of Shoemaker's studies on hyperdynamic resuscitation. Other methods included in Table 6 are still primarily research tools. The advent of a reliable resuscitation end-point will greatly aid the design of future trials.

Conclusions

Fluid resuscitation in burns should be commenced by the emergency practitioner prior to transfer to a specialist unit. In the acute setting, prior to the availability of more invasive monitoring (if warranted), the Parkland formula remains a useful tool. One must, initially at least, rely on traditional non-invasive physiological parameters to guide fluid therapy.

Ultimately, all fluids advocated are effective in restoring circulatory volume in the first 12-24 hours following burn injury for most patients. However, one should consider the use of alternative solutions and fluid regimes in those with severe and concomitant injuries, limited physiological reserve (children and the elderly) and those who are refractory to initial fluid resuscitation attempts. Identification of these patients will become a vital part of modern burns management.

One of the greatest impediments to the advance of burn resuscitation is the lack of a robust evidence base. This is reflected in the conflicting views and variations in burns fluid resuscitation practice seen across the UK, Europe and USA. Methods to identify subgroups of burns patients and the use of the same end-points and physiological protocols will aid in the comparison of treatment modalities. The current development of the National Burn Injury Database is an encouraging step forward.

In summary, the challenges that face the 21st century multidisciplinary burn team are to:

1. Achieve specific inflammatory mediator attenuation to minimise burn shock and oedema formation;

2. Discover the optimal fluid, or combination of fluids, that enables adequate tissue perfusion but that also reduces burn oedema and restores electrolyte balance and proteins;
3. Discover a reliable resuscitation end-point that is tailored to the patient, and
4. Obtain a robust evidence base to allow evaluation and comparison of outcomes.

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